

SEMICONDUCTOR VIDEO AMPLIFIERS FOR MONOCHROME AND COLOR TV RECEIVERS

by Derek Bray*

INTRODUCTION

Much has been written on video amplifiers suitable for high-level voltage drive to display tubes.¹⁻⁵

Those areas requiring display tubes in the television industry are of specific interest here. There are many different applications which can be considered within this field. These include TV camera viewfinders; TV studio picture monitors; small-screen, black and white TV receivers; large-screen, black and white TV receivers; small-screen, color TV receivers; large-screen color TV receivers; and closed-circuit TV monitors.

Although all these applications relate to television picture tubes, there are tremendous differences in the overall circuit and performance specifications, ranging from the relatively relaxed requirements for small-screen, black and white receivers to the stringent requirements for TV studio picture monitors and closed-circuit TV monitors. This paper will discuss these requirements, present some basic design information, and give some practical circuits relating to each of these applications.

VIDEO AMPLIFIER REQUIREMENTS

The bandwidth and voltage drive requirements for eight different applications are shown in Table 1. This table is self-explanatory; but for those not familiar with video amplifiers, the following explanations are given.

A 3-MHz bandwidth is normally required for reasonable quality reception in TV receivers. The differing voltage drive requirements for the first three applications are due to variations in tube size and in gun construction. The

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TABLE I.

Basic Video Amplifier Specifications.

Application	Bandwidth (MHz)	Output Voltage (peak-to-peak)
Small-Screen, Black and White TV Receiver	3	80
Large-Screen, Black and White TV Receiver	3	120
Large-Screen, Color TV - luminance	3	200
Large-Screen, Color TV - Chrominance	500 kHz	200
Single-Gun Chromatron Color TV	15	60
TV Camera Viewfinder	8	60
TV Studio Picture Monitor	8	100
Closed-Circuit TV Monitor	30	80

500-kHz bandwidth for the color chrominance channel is entirely adequate for signals containing color information only, since the eye is less sensitive to color brightness than to black and white changes. For the chromatron, single-gun tube, a 15-MHz bandwidth is required to accommodate fourth harmonic signals of the color subcarrier frequency.⁶

Bandwidth requirements for TV studios are primarily determined by the need to have equipment which will give a distortion-free display of the best possible output from a TV camera. The CCTV 30-MHz bandwidth is determined by the higher scanning rate sometimes employed and the need to provide much better resolution than a conventional TV broadcast system.

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BASIC DESIGN INFORMATION

In the design of transistor video amplifiers, it is important to know certain transistor parameters and how these parameters contribute to the overall performance.

Common Emitter Amplifier

The simplest type of video amplifier, shown in Fig. 1, can be analyzed by the use of the well-known, common-emitter,

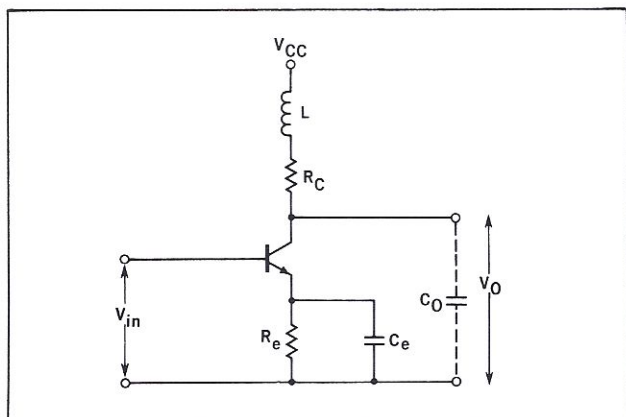


Fig. 1. Basic video amplifier.

hybrid-pi, equivalent network shown in Fig. 2, which results in the overall equivalent circuit shown in Fig. 3.

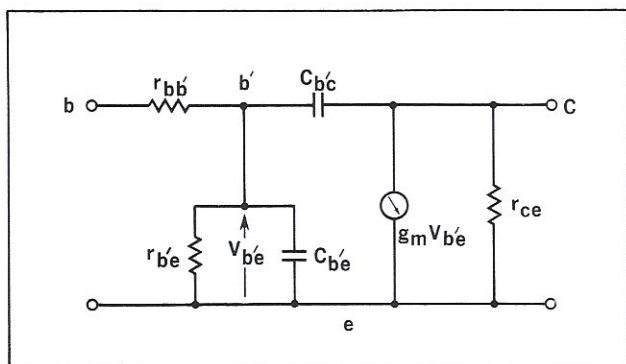


Fig. 2. Simplified hybrid-PI equivalent circuit.

The design procedure can be split into two parts; (a) consideration of the input circuit and (b) consideration of the output circuit. A simplified analysis of a video amplifier circuit is given in Appendix I, resulting in the following design equations:

Input time constant,

$$T_{in} = \frac{C_{be}' + C_{bc}' g_m R_L + r_{be}' (R_s + r_{bb}')}{R_s + r_{bb}' + r_{be}' (1 + g_m R_e)} \quad (1)$$

$$\text{Output time constant, } T_{out} = \frac{R_L C_0}{1.82} \text{ for a 2.5\% overshoot.} \quad (2)$$

The overall amplifier response will be maximally flat if the emitter time constant, $C_e R_e$, exactly compensates for the effect of both input and output time constants.

$$R_e C_e = \sqrt{T_{in}^2 + T_{out}^2} \quad (3)$$

The base-emitter capacitance, C_{be}' , can be related to the f_T of the transistor by

$$C_{be}' = \frac{\beta}{2\pi r_{be}' f_T} = \frac{1}{2\pi r_e f_T} \quad (4)$$

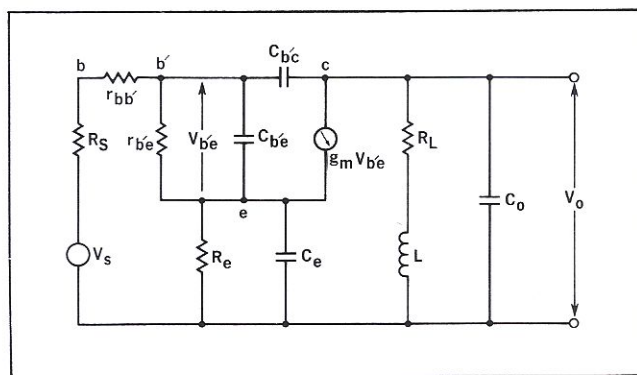


Fig. 3. Common-emitter amplifier equivalent circuit.

For the largest possible bandwidth, it is necessary to have a device with the following characteristics:

- r_{bb}' as small as possible
- f_T as large as possible
- C_{bc}' as small as possible
- C_{ob} as small as possible
- High power capability for small R_L

Small input time constants are guaranteed by (a) through (c); small output time constants, by (d) and (e). Other requirements for a wide bandwidth are:

- Low source impedance
- Output peaking networks
- Emitter peaking networks.

This basic circuit will be used in several of the practical applications discussed later.

Feedback Amplifier

An emitter-follower driver stage, to obtain the desired low-impedance drive, together with the common emitter output stage just described, uses one low-voltage and one high-

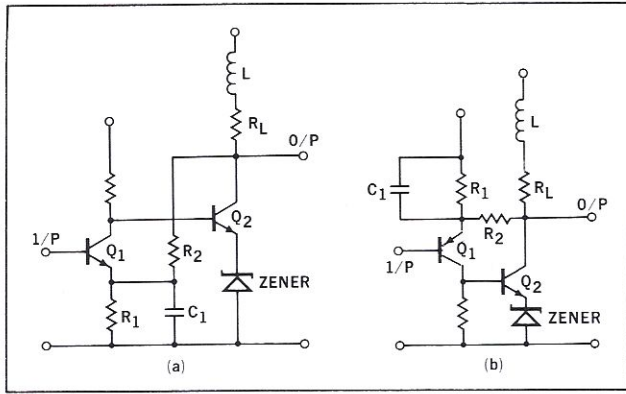


Fig. 4. Feedback pair video output amplifiers.

voltage transistor. Two similar transistors can be used in an alternative way in the feedback pair circuits shown in Fig. 4. The circuit of Fig. 4(a) uses two NPN transistors and 4(b) uses a PNP-NPN combination. Results from an analysis of a more complicated circuit⁷ can be applied to the basic circuit of Fig. 4, as follows:

$$\text{Open-loop low-frequency voltage gain } A \approx \frac{B_2 R_L}{R_1}$$

$$\text{Low-frequency voltage gain } A_0 \approx \frac{R_1 + R_2}{R_1}$$

$$\text{Low-frequency output impedance } Z_0 = \frac{R_1 + R_2}{\beta_2}$$

In a practical case, the high-frequency performance will be determined by transistor Q_2 since it is always possible to select Q_1 to have a very high f_T and low C_{be}' .

The high-frequency performance of the feedback pair circuit is analyzed in Appendix II, giving

$$\text{3-dB cutoff frequency with } L = 0, C_1 = 0$$

$$f_0 = 2\pi \frac{f_T \beta_2 R_L}{(1 + \beta_1 R_1 C_{bc}' f_T) (R_1 + R_2)} \quad (5)$$

This corresponds to a time constant,

$$T_1 = r_{be}' (C_{be}' + g_m R_L C_{bc}') \frac{R_1 + R_2}{\beta_2 R_L} \quad (6)$$

Where all parameters refer to transistor Q_2 .

Similarly, the output time constant, with $L = 0.4 C_0 R_L^2$

$$T_0 = \frac{C_0 (R_1 + R_2)}{1.82 \beta_2} \quad (7)$$

The capacitor, C_1 , can now be chosen to compensate for both T_1 and T_0 , giving:

$$C_1 R_1 = \sqrt{T_1^2 + T_0^2}$$

This type of circuit can be used where good linearity and wide bandwidths are required, as in a television camera.

Output Voltage Capability

In any single transistor output stage, irrespective of whether negative feedback is used or not, there is a limit to the current available for signal polarities causing an increase in collector voltage. In an extreme case, the transistor will cut off and the load resistance will have to supply the current required to charge the capacitance load.

Considering a sine-wave output, the maximum current occurs at the maximum rate of voltage change across the capacitance load; i.e., when $\cos \omega t = 1$ in the following expression, and V_0 is equal to the peak-to-peak sine-wave voltage output.

$$I_c = C V_0 \frac{\pi f}{\sqrt{2}} \cos \omega t \quad (8)$$

For normal conditions, this will occur with half the supply voltage across the transistor,

$$I_{C \max} = \frac{V_{CC}}{2 R_{L1}} = C_0 V_0 \frac{\pi f}{\sqrt{2}}$$

$$R_{L1} = \frac{\sqrt{2} V_{CC}}{V_0} \frac{1}{2 \pi f C_0} \quad (9)$$

The load resistance can also be calculated by consideration of bandwidth requirements for a common emitter stage using a transistor with a high value of f_T .

$$f_{3 \text{ dB}} = \frac{1.7}{2 R_{L1} C_0}, \text{ for } L = 0.4 C_0 R_{L1}^2$$

$$\therefore R_{L1} = \frac{1.7}{2 \pi C_0 f_{3 \text{ dB}}} \quad (10)$$

For normal operating conditions, $V_{CC} \approx \sqrt{2} V_0$

$$\therefore R_{L1} = \frac{1}{\pi f C_0} \quad (11)$$

and

$$\therefore \frac{R_{L1}}{R_{L2}} = 0.85 \quad (12)$$

This indicates that any non-feedback design, based on bandwidth requirements only, will meet the large signal conditions. However, if the effective low-output impedance is obtained by the use of negative feedback, care must still be taken to satisfy the condition for R_{L_1} .

There is a considerable bandwidth advantage in a feedback design if the signal swing at the high frequencies is reduced. Under these circumstances, advantage can be taken of the low-output impedance to give better frequency response.

PRACTICAL CIRCUITS

Small Screen, Black and White Receiver

The schematic shown in Fig. 5 is a typical circuit for black and white TV, with screen sizes up to approximately 12 inches diagonal. The circuit comprises an emitter follower, Q_1 , driving a common emitter output stage Q_2 .

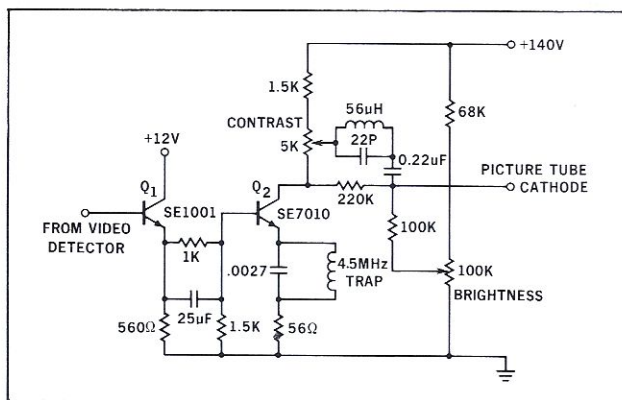


Fig. 5. Small-screen, black and white receiver.

Additional circuitry includes 4.5-MHz sound traps in both the emitter and collector circuits of Q_2 , and contrast and brightness controls in the collector of Q_2 . The additional collector circuits contribute a significant stray capacity loading on the collector of Q_2 , with the result that the overall circuit bandwidth is limited to about 2.5 MHz. This, coupled with an output capability of 80 volts peak-to-peak, is still adequate for a small screen. No additional video peaking is included in either the emitter or the collector of Q_2 , since the resolution of the eye would not allow any additional picture detail to be observed except with close-up viewing of the small screen. Both input and output circuits are partially a. c. coupled to reduce high-voltage regulation requirements on peak, white signals.

Large Screen, Black and White Receiver

For larger black and white screen sizes, a circuit similar to the one shown in Fig. 6 can be used.⁸ Here d.c. coupling is preserved throughout with the emitter follower Q_1 driving a common-emitter output stage, Q_2 . The 4.5-MHz sound trap and sound take-off circuit is located in

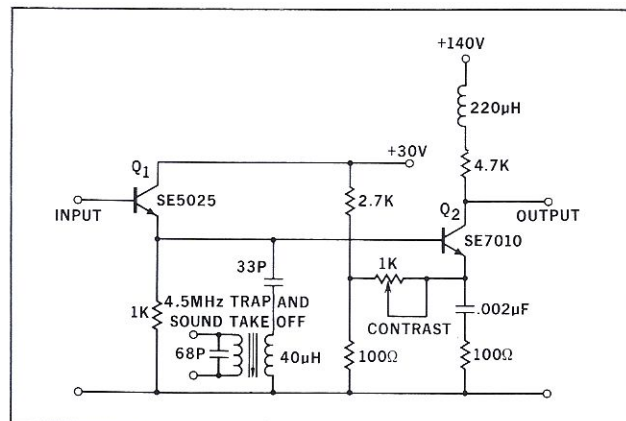


Fig. 6. Large-screen, black and white receiver.

the base of Q_2 , and the contrast control is in the emitter of Q_2 . This allows maximum bandwidth to be obtained by keeping the capacitive load on the collector of Q_2 to a minimum. Additional peaking is also provided in the emitter circuit of Q_2 . Brightness control is usually provided on the grid of the picture tube.

Camera Viewfinder and Picture Monitor Video Amplifiers

In television studios, high-definition displays are required to provide an overall check on picture quality before transmission. Fig. 7 is a schematic of an amplifier⁹ which can be used for either a large-screen (19-inch) display or alternatively in a television camera for the viewfinder display. Bandwidths of greater than 6 MHz with less than ± 0.1 dB variation are required with an output capability of up to 100 volts peak-to-peak. This requirement is best satisfied by using a feedback circuit consisting of Q_1 and Q_2 .

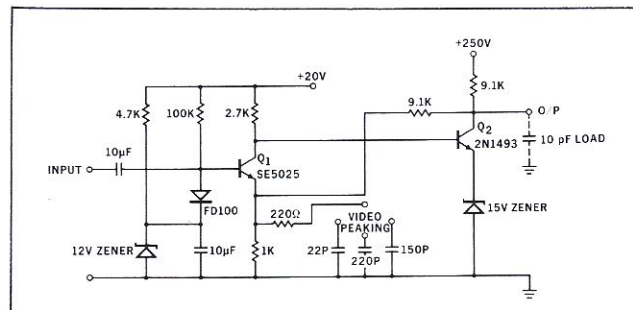
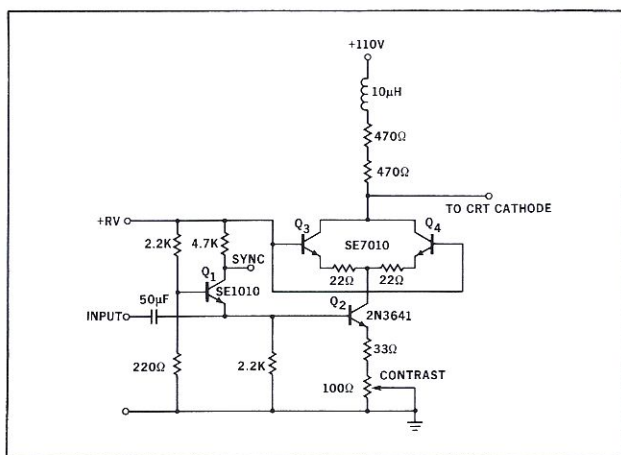


Fig. 7. Camera viewfinder and picture monitor video amplifier.

Single Gun Chromatron Video Amplifier

The schematic shown in Fig. 8 was used as the final video amplifier for a 1,2,4 display on a single-gun chromatron 12-inch color picture tube.⁶ The 15-MHz bandwidth required to transmit the fourth harmonic component of the color subcarrier frequency (3.58 MHz) is obtained by using a low-load impedance and a cascode-connected amplifier.



The common emitter amplifier, Q_2 , is a high f_T device providing a high cut-off frequency. Q_3 and Q_4 are parallel-connected, grounded base stages to provide sharing of both current and power dissipation, since a single device is not adequate. Simple collector shunt peaking can be used, since the capacitive load is less than 10 pF.

Large-Screen, Shadowmask Luminance Amplifier

Due to the additional components in the collector of Q_2 , giving a total capacitive load of 40 pF, the video bandwidth

(a) LUMINANCE AMPLIFIER

(b) COLOR DIFFERENCE AMPLIFIER

Large-Screen, Shadowmask, Color-Difference Amplifiers

Large-Screen, Shadowmask, RGB System

The circuit diagram illustrates the internal components of a 6300A color television receiver. It is divided into three main functional blocks: the power supply, the video amplifier, and the color control section.

- Power Supply Section:** A -250V AC input is connected to a 470 μ H inductor. This is followed by a pi-network of three 10K resistors. The circuit then branches into three parallel diode paths, each consisting of a 470 μ F capacitor in series with an FD200 diode (labeled D₁, D₂, and D₃). The output of this section provides three cathode voltages: R (1K Ω), G (1K Ω), and B (1K Ω), which are connected to the picture tube cathodes.
- Video Amplifier Section:** This section consists of three 2N3638A transistors (Q₁, Q₂, and Q₃). Q₁ is the first video amplifier stage, receiving Y (luminance) and B-Y signals. Its output is connected to the B-Y input of Q₂. Q₂ is the second video amplifier stage, which also receives a G-Y signal. The output of Q₂ is connected to the G-Y input of Q₃. Q₃ is the third video amplifier stage, which receives a Y signal. The outputs of Q₁, Q₂, and Q₃ are connected to the R, G, and B inputs of the picture tube, respectively.
- Color Control Section:** This section includes a 2N3638A transistor (Q₄) and a 100 μ F capacitor. The input to Q₄ is connected to the 100 μ F capacitor, which is in turn connected to the 100 μ F capacitor in the power supply section. The output of Q₄ is connected to the 100 μ F capacitor in the power supply section.

Fig. 10. Large-screen, color RGB video amplifiers.

Q_3 , respectively, resulting in low-level matrixing and an RGB output from the respective collectors.

Capacitive loading of the collector circuits is kept to a minimum by providing grey-scale tracking controls in the emitters of Q_1 and Q_2 instead of in the collector circuits. In addition, each output contributes to the total capacitive charging current required and a single-shunt peaking coil can be used. A bandwidth in excess of 3 MHz can be easily obtained.

Protection against tube arcing is achieved by (a) decoupling of the picture tube grids, and (b) by addition of the 1-k limiting resistors and catching diodes in the collector circuits of the three output transistors.

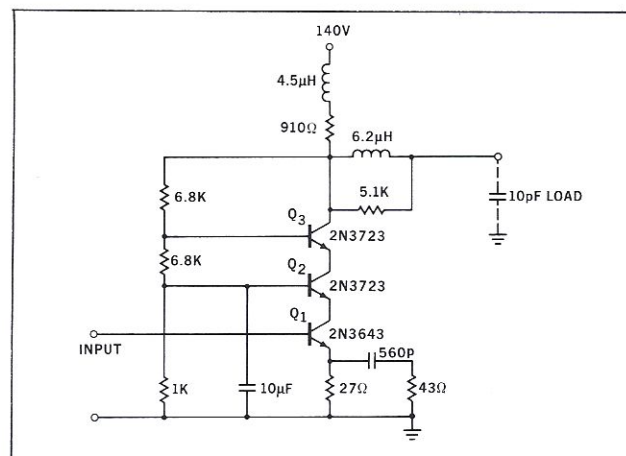


Fig. 11. Closed-circuit, high-resolution, video amplifiers.

Closed-Circuit, High-Resolution Video Amplifier

The high resolution of 1000 lines in both horizontal and vertical directions, required by some closed-circuit TV systems, dictates the need for a video amplifier with a 30-MHz bandwidth. This can only be achieved by using low-capacity, high f_T devices. Such devices are usually limited to a relatively low breakdown voltage, and it is necessary to stack devices to provide voltage sharing as shown in Fig. 11.

Q_1 acts as a common-emitter amplifier feeding into a composite common-base stage comprised of Q_2 and Q_3 . Negative feedback via the two 6.8-k resistors on the bases of Q_2 and Q_3 ensure that the signal voltage swing is equally divided between Q_2 and Q_3 . Conventional series, shunt peaking is employed in the collector circuit of Q_3 to obtain maximum bandwidth. Additional emitter peaking in Q_1 also improves the overall circuit bandwidth.

An undistorted 3-dB bandwidth of 30 MHz at a signal level of 20 volts peak-to-peak can be obtained from this circuit with an output capability of 80 volts peak-to-peak at low frequencies.

TRANSISTOR REQUIREMENTS

Having discussed the basic design problems and some practical circuits, it would be interesting to know what kind of transistors are required for each application. For the practical circuits considered, this information is summarized in Table 2.

CONCLUSION

From Table 2 it can be seen that devices are available for all applications, with the exception of the RGB color system. A transistor designed to meet these particular requirements could also be used in black and white receivers, providing a universal device for video output applications in the consumer industry. Future technological improvements could result in lower capacity and higher f_T transistors, which would allow wider bandwidths and better resolution to be obtained more economically.

TABLE II.

Video Output Transistor Requirements For TV Display Systems

Application	Bandwidth (MHz)	Output Voltage (peak-to-peak)	V_{CEO} (Volts)	f_T mm (MHz)	C_{re} (pF)	C_{ob} (pF)	Power Diss. (Watts)	Device
Small Screen, Black & White	3	80	120	40	2.5	3.5	1.0	SE7010
Large Screen, Black & White	3	120	150	40	2.5	3.5	1.5	SE7010
Camera Viewfinder and studio Monitor	8	100	100	200	5	6	1.5	2N1493 2N3723
Chromatron Video Amplifier	15	60	80	40	2.5	3.5	1.5	SE7010 2N3723
Luminance Amplifier	2.5	200	250	30	8	12	3.0	SE7020
Chroma Amplifier	0.5	200	250	30	8	12	1.0	SE7020
RGB Amplifier	3.0	200	250	60	3.0	5.0	1.5	Experimental
Closed Circuit TV	30	80	80	250	7.0	9.0	1.5	2N3723

ACKNOWLEDGMENTS

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APPENDIX I.

Analysis of a Transistor Video Amplifier

The simplified equivalent circuit of the amplifier stage shown in Fig. 1 is given in Fig. 3.

Input Time Constant

At low frequencies, the input impedance of the intrinsic transistor can be represented as a resistance R_{in} in parallel with a capacitance C_{in} , where

$$C_{in} = \frac{C_1}{1 + gm R_e}$$

and $R_{in} = r_{be}' (1 + gm R_e)$

and $C_1 = C_{be}' + C_{bc}' gm R_L$.

The base-spreading resistance, r_{bb}' , can be considered as part of the generator or source resistance, $R_g = R_s + r_{bb}'$.

The input circuit time constant can thus be approximated to

$$T_{in} = C_{in} \frac{R_g R_{in}}{R_g + R_{in}}$$

$$\therefore T_{in} = \frac{(C_{be}' + C_{bc}' gm R_L) (R_s + R_{bb}') r_{be}'}{R_s + r_{bb}' + r_{be}' (1 + gm R_e)}$$

Output Time Constant

With no output peaking ($L = 0$), the output time constant can be approximated to

$$T_{out} = R_L C_o$$

where $C_o = C_{bc}' + C_{Load} + C_{Wiring}$.

For a shunt peaked stage, the following table gives bandwidth, rise-time improvements, and overshoots to a square-wave response for various values of inductance.

TABLE III.

Peaking Responses of Selected Inductance Values

Inductance	Bandwidth Improvement Ratio	Rise-Time Improvement Ratio	Overshoot (%)
0	1.0	1.0	0
$0.3 C_o R_L^2$	1.5	1.57	0.5
$0.35 C_o R_L^2$	1.62	1.74	1.25
$0.4 C_o R_L^2$	1.70	1.82	2.5
$0.45 C_o R_L^2$	1.76	1.9	4.0
$0.5 C_o R_L$	1.8	2.0	6.5

Normally L is chosen so that overshoot is of the order of 2.5 percent; i.e., $L = 0.4 C_o R_L^2$, and the rise-time improvement ratio is 1.82.

The output time constant is therefore

$$T_{out} = \frac{R_L C_o}{1.82}$$

APPENDIX II.

High-Frequency Performance of a Feedback Pair

The open-loop, 3-dB cut-off frequency of the circuit of Fig. 4, excluding C_1 and L , is determined by the 3-dB cut-off of Q_2 when fed from a high-impedance source. With reference to Fig. 2, the input time constant of Q_2 is given by:

$$T_{in} = r'_{be} (C'_{be} + g_m R_L C'_{bc}).$$

This corresponds to a cut-off frequency with a resistive load of

$$f_0 = \frac{1}{2\pi T_{in}} = \frac{1}{2\pi r'_{be} (C'_{be} + g_m R_L C'_{bc})}$$

$$f_0 = \frac{f_T}{2\pi (1 + \beta R_L C'_{bc} f_T)}.$$

The closed-loop cut-off frequency with a resistive load is increased by approximately the same ratio as the gain is decreased.

$$\text{Closed-loop cut-off, } f_{C_0} = \left(\frac{f_T}{2\pi (1 + \beta R_L C'_{bc} f_T)} \right) \left(\frac{\beta R_L}{R_1 + R_2} \right)$$

The output time constant can be calculated by consideration of the open-loop response and gain reduction.

$$L = 0.4 C_0 R_L^2 \text{ (See Appendix I)}$$

$$T_{00} = \frac{R_L C_0}{1.82}, \text{ without feedback}$$

$$T_0 = \frac{R_L C_0}{1.82} \frac{R_1 + R_2}{B_2 R_L} \approx \frac{(R_1 + R_2) C_0}{1.82 B_2}, \text{ with feedback.}$$